TOWARDS A UNIFIED ORIGIN OF FORCES, FAMILIES AND MASS SCALES[†]

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ABSTRACT

In spite of the success of the conventional approach to grand unification as regards the meeting of the gauge coupling constants, it is expressed that the associated arbitrariness in the choice of the Higgs-sector parameters goes against the very grain of unification. Owing to this arbitrariness, the Higgs-exchange force is in fact still ununified. The superstring theories, following the assumption of elementary quarks, have not yet yielded the *right package* of Higgs-sector parameters, through any one of their plethora of solutions – a task that *a priori* seems a heavy burden.

A case is therefore made for an alternative approach to unification that is based on a *purely gauge origin of the fundamental forces*, and is thus devoid of the Higgs-sector altogether. This approach seems to call for the ideas of local supersymmetry and preons. The associated spectrum and forces may well have their origin within a superstring theory, which would, however, be relieved (in this case) from the burden of yielding the "right package" of Higgs-sector parameters, because the system has no Higgs sector. The advantage of the marriage of the ideas of local supersymmetry and preons, subject to two broad dynamical assumptions which are specified, are noted. These include true economy and viability as well as an understanding of the origins of (a) family-replication, (b) inter-family mass-hierarchy, and (c) diverse mass-scales which span from M_{Planck} to $m_W \sim m_t$ to m_e to m_ν. In short, the approach seems capable of providing *a unified origin of the forces, the families and the mass-scales.* In the process, the preonic approach provides the scope for synthesizing a rich variety of phenomena all of which could arise dynamically through one and the same tool – the SUSY metacolor force coupled with gravity – at the scale of $10^{11} GeV$. The phenomena include: (i) spontaneous violations of parity, CP, B-L and Peccei-Quinn symmetry, (ii) origin of heavy Majorana mass for ν_R, (iii) SUSY breaking, (iv) origins of even m_W, m_q and m_ℓ, as well as, (v) inflation and lepto/baryo-genesis.

Some intriguing experimental consequences of the new approach which could show at LEPI, LEPII and Tevatron and a *crucial prediction* which can be probed at the LHC and NLC are presented.

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1. Going Beyond the Standard Model

The standard model of particle physics (SM) has brought a good deal of synthesis in our understanding of the basic forces of nature, especially in comparison to its predecessors, and has turned out to be brilliantly successful in terms of its agreement with experiments. Yet, as recognized for sometime [1], it falls short as a fundamental theory because it introduces some 19 parameters. And it does not explain (i) family replication; (ii) the coexistence of the two kinds of matter: quarks *and* leptons; (iii) the coexistence of the electroweak *and* the QCD forces with their hierarchical strengths $g_1 \ll g_2 \ll g_3$, as observed at low energies; (iv) quantization of electric charge; (v) inter and intrafamily mass-hierarchies - *i.e.*, $m_{u,d,e} \ll m_{c,s,\mu} \ll m_{t,b,\tau}$ and $m_b \ll m_t$, etc. - reflected by ratios such as $(m_u/m_t) \sim 10^{-4}$, $(m_c/m_t) \sim 10^{-2}$ and $(m_b/m_t) \sim \frac{1}{35}$; and (vi) the origin of diverse mass scales that span over more than 27 orders of magnitude from M_{Planck} to m_W to m_e to m_ν, whose ratios involve very small numbers such as $(m_W/M_{Pl}) \sim 10^{-17}$, $(m_e/M_{Pl}) \sim 10^{-22}$ and $(m_\nu/M_{Pl}) < 10^{-27}$. There are in addition the two most basic questions: (vii) how does gravity fit into the whole scheme, especially in the context of a good quantum theory?, and (viii) why is the cosmological constant so small or zero?

These issues constitute at present some of the major puzzles of particle physics and provide motivations for contemplating new physics beyond the standard model which should shed light on them. The ideas which have been proposed and which do show promise to resolve at least some of these puzzles include:

(1) **Grand Unification**: The hypothesis of grand unification, which proposes an underlying unity of the fundamental particles and their forces [1,2,3], appears attractive because it explains at once (i) the quantization of electric charge, (ii) the existence of quarks *and* leptons with $Q_e = -Q_p$, and (iii) the existence of the strong, the electromagnetic and the weak forces with $g_3 \gg g_2 \gg g_1$ at low energies, but $g_3 = g_2 = g_1$ at high energies. These are among the puzzles listed above and grand unification resolves all three. *Therefore I believe that the central concept of grand unification is, very likely, a step in the right direction.* By itself, it does not address, however, the remaining puzzles listed above, including the issues of family replication and origin of mass-hierarchies.

(2) **Supersymmetry**: This is the symmetry that relates fermions to bosons[4]. As a local symmetry, it is attractive because it implies the existence of gravity. It has the additional virtue that it helps maintain a large hierarchy in mass-ratios such as $(m_\phi/M_U) \sim 10^{-14}$ and $(m_\phi/M_{p\ell}) \sim 10^{-17}$, without the need for fine tuning, provided, however, such ratios are put in by hand. Thus it provides a technical resolution of the gauge hierarchy problem, *but by itself does not explain the origin of the large hierarchies.*

(3) **Compositeness**: Here there are *two distinct suggestions*:

(a) <u>Technicolor</u>: The idea of technicolor [5] proposes that the Higgs bosons are composite but quarks and leptons are still elementary. Despite the attractive feature of dynamical symmetry breaking which eliminates elementary Higgs bosons and thereby the arbitrary parameters which go with them, this idea is excluded, at least in its simpler versions, owing to conflicts with flavor-changing neutral current processes and oblique electroweak corrections. The so-called walking technicolor models may be arranged to avoid some of these conflicts at the expense, however, of excessive proliferation in elementary constituents. Furthermore, as a generic feature, none of these models seem capable of addressing any of the basic issues

listed above, including those of family replication and fermion mass-hierarchies. Nor do they go well with the hypothesis of a unity of the basic forces.

(b) Preons: By contrast, the idea of preonic compositeness which proposes that not just the Higgs bosons but also the quarks and the leptons are composites of a *common* set of constituents called "preons" seems much more promising. Utilizing supersymmetry to its advantage, the preonic approach has evolved over the last few years to acquire a form [6,7,8,9] which is (a) far more economical in field-content and especially in parameters than either the technicolor or the conventional grand unification models, and, (b) is viable. Most important, utilizing primarily the symmetries of the theory (rather than detailed dynamics) and the peculiarities of SUSY QCD as regards forbiddeness of SUSY-breaking, in the absence of gravity, the preonic approach provides simple explanations for the desired protection of composite quark-lepton masses and at the same time for the origins of family-replication, inter-family mass-hierarchy and diverse mass scales. It also provides several testable predictions. In this sense, though still unconventional, the preonic approach shows promise in being able to address certain fundamental issues. I will return to it shortly.

(4) **Superstrings**: Last but not least, the idea of superstrings [10] proposes that the elementary entities are not truly pointlike but are extended stringlike objects with sizes $\sim (M_{Planck})^{-1} \sim 10^{-33}$ cm. This idea appears to be most promising in providing a unified theory of all the forces of nature including gravity and yielding a well-behaved quantum theory of gravity. In principle, assuming that quarks, leptons and Higgs bosons are elementary, a suitable superstring theory could also account for the origin of the three families and the Higgs bosons at the string unification scale, as well as explain all the parameters of the SM. But in practice, this has not happened as yet. Some general stumbling blocks of string theories are associated with the problems of (i) a choice of the ground state (the vacuum) from among the many solutions and (ii) understanding supersymmetry breaking.

The ideas listed above are, of course, not mutually exclusive. In fact the superstring theories already comprise local supersymmetry and the central idea of grand unification. It remains to be seen, however, whether they give rise, in accord with the standard belief, to elementary quarks and leptons, or alternatively to a set of substructure fields – the preons. In the following, I first recall the status of conventional grand unification, and then provide a perspective as well as motivations for an alternative approach to grand unification, based on the idea of preons.

2. Grand Unification in the Conventional Approach
(A) The SU(5) vs. SU(4)-Color Routes: A Distinction through Neutrinos

By "Conventional approach" to grand unification I mean the one in which quarks and leptons – and traditionally the Higgs bosons as well – are assumed to be elementary [1,2,3]. Within this approach, there are two distinct routes to higher unification: (i) the SU(4)-color route [1] and (ii) SU(5)[2]. Insisting on a compelling reason for charge – quantization, the former naturally introduces the left-right symmetric gauge structure $G_{224} = SU(2)_L \times SU(2)_R \times SU(4)^C_{L+R}$ [1], which in turn may be embedded in anomaly-free simple groups like SO(10) or E_6 [11].

While the two routes share some important common features, such as quark-lepton unification and unification of gauge coupling constants (see discussions below), there are two major conceptual and practical distinctions between them. SU(5), *viewed as fundamental*,

(rather than part of SO(10), (i) violates parity explicitly and (ii) does not have a compelling reason for the existence of ν_R's and therefore for the ν_L's to be massive. Even allowing for higher dimensional operators induced by Planck scale physics of the type $\nu_L\nu_L\langle\phi\rangle\langle\phi\rangle/M$ one obtains $m(\nu_L) \sim 10^{-5} - 10^{-4}eV$ for $M \sim M_{Pl} \sim 10^{19} - 10^{18}GeV$, which is too small for neutrinos to serve as HDM and (perhaps) a bit too small even for them to be relevant to the MSW explanation of the solar neutrino puzzle.

By contrast, the SU(4)-color route in the context of the core symmetry G_{224} (and therefore higher symmetries like SO(10) or E_6 as well) (i) proposes parity to be exact at high energies which is violated only spontaneously [12] and (ii) *requires* the existence of ν_R's and therefore neutrinos to have at least Dirac masses. Together with heavy Majorana masses for ν_R's of order $10^{11} - 10^{12}GeV$, which can arise spontaneously together with $SU(2)_R$-breaking in a variety of ways [13], one obtains the light see-saw neutrino masses $m(\nu_L^i) \simeq (m(\nu^i)_{Dirac}^2/M_{\nu_R})$. This yields the mass-pattern: $m(\nu_L^e) \simeq 10^{-8} \ eV$, $m(\nu_L^\mu) \simeq (10^{-3} - 10^{-1}) \ eV$ and $m(\nu_L^\tau) \simeq$ (1 to 30) eV, which goes well both with the MSW solution for the solar neutrino puzzle and with the candidacy of ν_τ for HDM. Thus, if neutrino masses settle at the presently indicated values, especially if at least one of them has a mass of order one to few electron volts, as suggested by the need for HDM, one would have a strong indication in favor of the SU(4)-color route and left-right symmetry, as opposed to the SU(5)-route.

The other distinguishing feature of SU(4)-color is that it gauges B-L as a local symmetry. Following the old arguments of Lee and Yang, based on Eötvos-type experiments, it follows that the massless gauge particle coupled to B-L must acquire mass spontaneously and thereby B-L must break spontaneously. Such B-L violations at an intermediate scale ($\sim 10^{11} \ GeV$) may well be necessary to implement baryogenesis, since electroweak effects erase B-L conserving baryon excess, generated at higher temperatures. *Because of these desirable features, I believe that the symmetry group G_{224} is likely to be part of a fundamental theory.* It turns out that even the preonic approach to unification (to be presented here) relies heavily on the symmetry group G_{224} and thus enjoys the same advantages, as regards neutrino masses and B-L violation. I now turn to the two central features of grand unification.

(B)   Meeting of the Coupling Constants and Proton Decay

It has been known for sometime that the dedicated proton decay searches at the IMB and the Kamiokande detectors [14], and more recently the precision measurements of the SM coupling constants (in particular $\sin^2\hat{\theta}_W$) at LEP [15] put severe constraints on grand unification models without supersymmetry. Owing to such constraints, the non-SUSY minimal SU(5) and, for similar reasons, the one-step breaking non-SUSY SO(10)-model, as well, are now excluded beyond a shadow of doubt.

But the idea of the union of the coupling constants g_1, g_2, and g_3 can well materialize in accord with the LEP data, if one invokes supersymmetry [16,17,18] into minimal SU(5) or SO(10). See Fig. 1, which shows the *impressive meeting* of the three coupling constants of the minimal supersymmetric standard model (MSSM) with an assumed SUSY-threshold around 1 TeV. Such a model can, of course, be embedded within a minimal SUSY SU(5) or SO(10) model, which would provide the rationale for the meeting of the coupling constants at a scale $M_U \approx 2 \times 10^{16}$ GeV.

The fact that the coupling constants meet in the context of these models is reflected by the excellent agreement of their predicted value of $[\sin^2\hat{\theta}_W(m_z)_{theory} = \cdot2325 \pm \cdot005$

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(using $\alpha_s(m_z) = \cdot 12 \pm \cdot 01$) with that determined at LEP: $[\sin^2 \hat{\theta}_W(m_z)]_{expt.} = \cdot 2316 \pm \cdot 0003$. In SUSY SU(5) or SO(10), dimension 5 operators do in general pose problems for proton decay. But the relevant parameters of the SUSY-space can be arranged to avoid conflict with experiments [19]. The SUSY-extensions of SU(5) or SO(10) typically lead to prominent strange particle decay modes, e.g., $p \to \bar{\nu} K^+$ and $n \to \bar{\nu} K^0$, while a 2-step breaking of SO(10) via the intermediate symmetry G_{224} can also lead to prominent $\Delta(B-L) = -2$ decay modes of the nucleon via Higgs exchanges such as $p \to e^- \pi^+ \pi^+$ and $n \to e^- \pi^+$ and even $n \to e^- e^+ \nu_e$, etc. in addition to the canonical $e^+ \pi^0$-mode [20].

It is encouraging that the super-Kamiokande (to be completed in April 1996) is expected to be sensitive to the $e^+ \pi^0$ mode up to partial lifetimes of few $\times 10^{34}$ years, to the $\bar{\nu} K^+$ and $\bar{\nu} K^0$ modes with partial lifetimes $\leq 10^{34}$ years and to the non-canonical $n \to e^- e^+ \nu_e$ and $p \to e^- \pi^+ \pi^+$ modes with partial lifetimes $< 10^{33}$ years. Thus the super-Kamiokande, together with other forthcoming facilities, in particular, ICARUS, provide a *big ray of hope* that first of all one will be able to probe much deeper into neutrino physics in the near future and second proton-decay may even be discovered within the twentieth century.

(C) Questioning the Conventional Approach

Focusing attention on the meeting of the coupling constants (Fig. 1), the question arises: To what extent does this meeting reflect the "truth" or is it somehow deceptive? There are two reasons why such a question is in order.

(1) First, the unity of forces reflected by the meeting of the coupling constants in SUSY SU(5) or SO(10) is truly incomplete, because it comprises only the gauge forces, but not the Higgs-exchange forces. *The latter are still governed by many arbitrary parameters – i.e., the masses, the quartic and the Yukawa couplings of the Higgs bosons – and are thus ununified.* Such arbitrariness goes against the central spirit of grand unification and has been the main reason in my mind since the 1970's (barring an important caveat due to the growth of superstring theories in the 1980's, see below) to consider seriously the possibility that the Higgses as well as the quarks and the leptons are composite. Furthermore, neither SUSY SU(5) nor SUSY SO(10), by itself, has the scope of explaining the origins of (a) the three families, (b) inter- and intra-family mass-splittings and (c) the hierarchical mass-scales: from M_{Planck} to m_ν.

(2) The second reason for questioning the conventional approach is this: one might have hoped that one of the two schemes – i.e., the minimal SUSY SU(5) or the SUSY SO(10)-model, or a broken "grand unified" symmetry with relations between its gauge couplings near the string scale, would emerge from one of the solutions of the superstring theories [10,21], which would yield not only the desired spectrum of quarks, leptons and Higgs bosons but also just the right parameters for the Higgs masses as well as their quartic and Yukawa couplings. While it seems highly nontrivial that so many widely varying parameters should come out in just the right way simply from topological and other constraints of string theories, it would of course be most remarkable if that did happen. *But so far it has not.* There are in fact a very large number of classically allowed degenerate 4D solutions of the superstring theories (Calabi-Yau, orbifold and free fermionic, etc.), although one is not yet able to choose between them. Notwithstanding this general difficulty of a choice, it is interesting that there are at least some three-family solutions. However, not a single one of these has yielded *either* a SUSY SU(5) or an SO(10)-symmetry, *or* a broken "grand unified" symmetry involving direct product of groups, with the desired spectrum *and* parameters, so as to explain the bizarre

pattern of fermion masses and mixings of the three families [27]. Note that for a string theory to yield elementary quarks, leptons and Higgs bosons, either the *entire package* of calculable parameters, which describe the masses of all the fermions and their mixings (subject to perturbative renormalization), should come out just right, or else the corresponding solution must be discarded. This no doubt is a *heavy burden*. For the case of the broken grand unified models, there is the additional difficulty that the grand unification scale of 2×10^{16} GeV obtained from low-energy extrapolation does not match the string unification scale of about 4×10^{17} GeV [23].

Thus, even if a certain superstring theory is the right starting point, and I believe it is, it is not at all clear, especially in view of the difficulties mentioned above, that it makes contact with the low-energy world by yielding elementary quarks, leptons and Higgs bosons. In this sense, it seems prudent to keep open the possibility that the meeting of the coupling constants in the context of conventional grand unification, which after all corresponds to predicting just one number – i.e., $sin^2\theta_W$ – correctly, may be fortuitous. Such a meeting should at least be viewed with caution as regards inferring the extent to which it reflects the "truth" because there are in fact alternative ways by which such a meeting can occur (see discussions below).

(D) Motivations for the Preonic Alternative

This brings me to consider an alternative approach to unification based on the ideas of preons and local supersymmetry [6,7,8,9]. Although the general idea of preons is old, the particular approach which I am about to present has evolved in the last few years. It is still unconventional, yet I believe, it is promising. Its lagrangian consists of only the minimal gauge interactions. *It is devoid altogether of the Higgs sector since its superpotential is zero owing to gauge and non-anomalous R-symmetry*, and therefore it is free from all the arbitrary mass, quartic and Yukawa coupling parameters which conventionally go with this sector. This brings *real economy*. In fact, the preon model possesses only three (or four) parameters which correspond to its gauge couplings (see below) and even these few would merge into one near the Planck scale if there is an underlying unity of forces as we envisage [24]. By contrast, the standard model has 19 and conventional SUSY grand unification models have over 15 parameters. As mentioned in the introductory chapter, in addition to economy, the main motivations for pursuing the preonic approach are that it provides simple explanations for (a) the protection of the masses of the composite quarks and leptons, (b) family replication, (c) inter-family mass-hierarchy ($m_{u,d,e} \ll m_{c,s,\mu} \ll m_{t,b,\tau}$) and (d) diverse mass-scales. It still preserves the central spirit of grand unification [24] and it is viable with respect to observed processes including flavor-changing neutral current processes (see remarks later) and oblique EW corrections.

Certain novel features in the dynamics of a class of SUSY QCD theories, in particular the forbidding of SUSY-breaking in the absence of gravity, and symmetries of the underlying preonic theory, play crucial roles in achieving these desired results (a)–(d). Furthermore, the approach provides some *crucial tests*, which can be performed at the LHC and possibly LEP 200, by which it can be vindicated if it is right or excluded if it is wrong. To present some of these results, I first need to recall a few salient features of the associated model.

3. The Preon Model: Challenges and Advantages

(A) Lagrangian: The model [6] is defined through an effective lagrangian, just below the

Planck scale, possessing $N = 1$ local supersymmetry and a gauge symmetry of the form $G_M \times G_{fc}$. Here the symmetry $G_M = SU(N)_M$ (or $SO(N)_M$) generates an asymptotically free metacolor gauge force which binds preons and G_{fc} denotes the flavor-color gauge symmetry, which is assumed to be either $G_{224} = SU(2)_L \times SU(2)_R \times SU(4)^C$ [1], or a subgroup of G_{224} containing $SU(2)_L \times U(1) \times SU(3)^C$. In what follows, to be specific, we assume $G_M = SU(N)_M$, although $SO(N)_M$ is a feasible choice. The gauge symmetry $G_M \times G_{fc}$ operates on a set of preonic constituents consisting of six positive and six negative *massless* chiral superfields $\Phi_\pm^a = (\varphi_{L,R}^a, \psi_{L,R}^a)$. Each of these transforms as the fundamental representation $\underline{N}$ of $G_M = SU(N)_M$. The index a runs over six values: $(x, y); (r, y, b, l)$, where (x, y) denote the two basic flavor-attributes (u, d) and (r, y, b, l) the four basic color-attributes of a quark-lepton family [1]. Thus $\Phi_+^{x,y}$ and $\Phi_-^{x,y}$ transform as doublets of $SU(2)_L$ and $SU(2)_R$ respectively, while both $\Phi_+^{r,y,b,l}$ and $\Phi_-^{r,y,b,l}$ transform as quartets of $SU(4)^C$. The effective lagrangian of this model turns out to possess only gauge and gravitational interactions. As a result, the model involves *at most only three or four parameters* (see below) corresponding to the coupling constants of the gauge symmetry $G_M \times G_{fc}$. For a number of reasons, including unity of forces, it turns out that N of $SU(N)_M$ should be between 6 and 4; thus $N_{flavors} = 6 = N$ or $N+1$ or $N+2$. Note, since "a" runs over six values, the global symmetry of the metacolor force is $G = SU(6)_L \times SU(6)_R \times U(1)_V \times U(1)_X$ where $U(1)_V$ is the preon number and $U(1)_X$ is the non-anomalous R symmetry [25]. In the presence of flavor-color interactions the $SU(6)_L \times SU(6)_R$ symmetry is, of course, approximate. Only its subgroup $G_{224} = SU(2)_L \times SU(2)_R \times SU(4)_{L+R}^c$ (or a subgroup of G_{224} containing the SM symmetry G_{213}), which is gauged, together with two global $U(1)$'s (up to QCD and EW anomalies), is exact.

Such a model has not yet been derived from a superstring theory, although there does not appear to be any bar, in principle in this regard especially in the context of four-dimensional fermionic constructions [21]. Even without such a derivation, if one introduces the economical preon-picture mentioned above through an effective lagrangian just below the Planck scale and assumes $N = 1$ local supersymmetry, one seems to be able to derive a number of advantages, subject to a few broad dynamical assumptions, which are stated below. These assumptions seem to me at least not implausible and, more important, they are *not* trivially related to the advantages.

(B) Dynamical Assumptions and Challenges: The *two main assumptions* of the model are: (1) The asymptotically free SUSY metacolor force with massless preons and (at least) one paired set of values of N_f and N, mentioned above, confines [26]. (2) As the metacolor (MC) force becomes strong at a scale Λ_M, which turns out to be of order 10^{11} GeV (see discussions later), it makes a few metacolor singlet composites, which include quarks and leptons (their replication and the protection of their masses will be justified on independent grounds). Furthermore, it makes a few MC singlet preonic condensates which break the (approximate) global symmetry G as well as its gauged subgroup $G_{fc} \subset G$ (G_{fc} can be as big as G_{224} and as small as G_{213}) to just the SM gauge symmetry G_{213} [27] at the scale Λ_M, while still preserving SUSY.

As a comment on the second assumption, it is of course possible to construct a few MC singlet SUSY-preserving condensates in the most attractive channels which would induce such a breaking pattern. In particular, in the preonic approach, one can construct a SUSY-preserving condensate $\langle \Delta_R \rangle$, transforming as $(1, 3_R, 10^{*c})$ of G_{224}. One assumes that this

condensate $\langle \Delta_R \rangle$ in fact forms [6]. If it forms, it would naturally be expected to be of order Λ_M since it conserves SUSY. As is well-known, such a condensate breaks G_{224} to G_{213}. It also breaks $L - R$ symmetry as well as $B - L$ so as to give a heavy Majorana mass to composite ν_R's of order Λ_M. But such a pattern of breaking (i.e., $G \rightarrow G_{213}$), which we assume, is by no means unique and clearly needs justification.

Indeed, it seems to be a major challenge in any approach to higher unification involving SUSY to know *why the preservation of the SM gauge symmetry and that of SUSY* seem to go together. And why are they *both* stable, at least relative to Planck scale physics? By the same token, why *must* their breakings get correlated? In the conventional approach to grand unification with SUSY, this feature is essentially put in by hand, to conform with observation, simply by a choice of the Higgs multiplets and their parameters. But even in the superstring theories, at the present stage of our understanding, there does not seem to be any *a priori* guarantee for such a correlation. For instance, either SUSY or the SM gauge symmetry or both might have broken already at the string unification scale. But it is assumed in the interest of progress, and rightly so, that the string vacuum somehow picks out from among many classically allowed solutions the four-dimensional space-time together with unbroken SUSY and the SM symmetry. We will proceed by assuming that in the preonic approach as well there exists such a correlation between the preservation of SUSY and that of the SM symmetry.

One further comment is in order. The breaking pattern assumed above (e.g., $G_{224} \rightarrow G_{213}$) presumes that a dynamical breaking of parity as well as of certain vectorial symmetries like "isospin" and preon number $U(1)_V$ would be permissible at least in some SUSY QCD theories. The breakdown of such symmetries is, of course, not permitted in ordinary QCD due to the no-go theorem of Vafa and Witten [28]. The proof of this theorem does not, however, apply to massless SUSY QCD both because of the presence of the gauge Yukawa interactions and also because of masslessness of the matter fields. It is tempting to conjecture that massless SUSY QCD (with N_F and N as listed above) in fact favors a dynamical breaking of parity as well as of "isospin" and $U(1)_V$. If true, there would be a compelling reason why nature violates these symmetries [29]. The proof of this conjecture remains a major challenge for the preonic approach and is part of the same task mentioned before – i.e., to show the stability of the breaking pattern: $(G \times (SUSY) \supset G_{224} \times SUSY) \rightarrow G_{213} \times (SUSY)$.

(C) **Advantages of Combining the Ideas of Preons and Supersymmetry**: I now list the advantages of the preonic approach. In addition to utmost economy in building blocks and parameters, as described above, they include:

(1) **Protection of the Masses of Quarks and Leptons**: Utilizing the Witten index theorem [30], which would forbid a dynamical breaking of SUSY in the class of theories under consideration, except for the presence of gravity, it is argued that chiral symmetry breaking preonic condensates like $\langle \bar{\psi} \psi \rangle$, as well as the metagaugino condensate $\langle \lambda \cdot \lambda \rangle$, both of which break SUSY, are necessarily damped by the factor (Λ_M / M_{Pl}), i.e.,

$$\langle \bar{\psi}^a \psi^a \rangle = a_{\psi_a} \Lambda_M^3 (\Lambda_M / M_{Pl})$$
$$\langle \lambda \cdot \lambda \rangle = a_\lambda \Lambda_M^3 (\Lambda_M / M_{Pl}) \tag{1}$$

where Λ_M denotes the scale parameter of the preonic metacolor force and M_{Pl} denotes the Planck mass [7], and a_{ψ_a} and a_λ are effective parameters of order unity. With a perturbative input value for the metacolor coupling near the Planck scale, the metacolor scale (Λ_M) is

naturally small compared to M_{Planck}. As a result, the masses of W and Z as well as those of the composite quarks and leptons are strongly damped compared to Λ_M by the factor (Λ_M/M_{Pl}). This explains why quarks and leptons are so light compared to their compositeness scale and thereby helps overcome the first major hurdle of composite models. In fact one obtains [6,7]: $m_W \sim m_t \sim (1/10)\Lambda_M(\Lambda_M/M_{Pl}) \sim 100 \ GeV$, where Λ_M is determined on independent grounds to lie around $10^{11} \ GeV$. The anomaly-matching condition of 't Hooft is satisfied trivially in our case because the unbroken symmetry is just G_{213} with the spectrum of G_{224} which is, however, anomaly-free. So the relevant anomalies vanish at the preon and the composite levels.

(2) Family Replication: One can argue plausibly that the composite operator giving massless spin-1/2 quark (or lepton) consists of a minimum of three constituents [31], two of which come from flavor and color-carrying preonic superfields and the third from the metagluon vector superfield $(v_\mu, \lambda, \bar{\lambda})$. Recognizing that in a SUSY theory, fermionic constituents can be interchanged by their boson partners (i.e. $\psi \leftrightarrow \varphi$ and $v_\mu \leftrightarrow \lambda$ or $\bar{\lambda}$ etc.), there exist several alternative three-particle combinations with identical quantum numbers, which can make a left-chiral $SU(2)_L$-doublet family q_L^i – e.g. (i) $\sigma_{\mu\nu}\psi_L^f\varphi_R^{c*}v_{\mu\nu}$, (ii) $\sigma^{\mu\nu}\varphi_L^f\psi_R^{c*}v_{\mu\nu}$, (iii) $\psi_L^f\psi_R^{c*}\lambda$ and (iv) $\varphi_L^f(\sigma^\mu\bar{\lambda})\partial_\mu\varphi_R^{c*}$. Here $f = x$ or y corresponds to up or down flavors and $c = (r, y, b)$ or ℓ corresponds to the four colors. *The plurality of these combinations, which stem because of SUSY, is in essence the origin of family-replication.* As mentioned before, by constructing composite superfields, Babu, Stremnitzer and I showed [8] that at the level of minimum dimensional composite operators (somewhat analogous to qqq for QCD) there are just three linearly independent chiral families $q_{L,R}^i$, and, in addition, two *vector-like families* $Q_{L,R}$ and $Q'_{L,R}$, which couple vectorially to W_L's and W_R's respectively. Each of these composite families is, of course, accompanied by its scalar superpartners. To sum up, we see that owing to a fermion-boson partnership in SUSY, the model provides a compelling reason for replication and at least some rationale, subject to the assumption of saturation at the level of minimum dimensional composite operators, as to why the number of chiral families is three. Clearly this last assumption needs further justification. Pending such a justification, however, let us still proceed to examine the masses of the fermions belonging to this system of *five families* – three chiral and two vector-like. We will see that such a system has some unique desirable features.

(3) **Inter-family Mass-Hierarchy**: First note that for the purposes of quantum numbers, the chiral and vector-like families can be represented by $q_L \sim$ "$\psi_L^f\varphi_R^{c*}v$", $q_R \sim$ "$\psi_R^f\varphi_L^{c*}v$", $Q_L \sim$ "$\psi_L^f\varphi_L^{c*}v$", $Q_R \sim$ "$\varphi_L^f\psi_L^{c*}v$", $Q'_L \sim$ "$\varphi_R^f\psi_R^{c*}v$" and $Q'_R \sim$ "$\psi_R^f\varphi_R^{c*}v$". Utilizing these compositions, one can see that the vector-families $Q_{L,R}$ and $Q'_{L,R}$ acquire relatively heavy masses through the metagaugino condensate $< \vec{\lambda} \cdot \vec{\lambda} >$ of order $a_\lambda\Lambda_M(\Lambda_M/M_{Pl}) \sim 1$ TeV, which are otherwise protected by the $U(1)_X$ quantum number of the SUSY theory. But the direct mass-terms of the three chiral families $m^{(o)}(q_L^i \to q_R^i)$ as well as the $Q - Q'$ mixing terms cannot be induced through either $< \vec{\lambda} \cdot \vec{\lambda} >$ or $< \bar{\psi}\psi >$. These receive small contributions at most of order (1/10-1) MeV from products of $< \bar{\psi}\psi >$ and $< \varphi^*\varphi >$ condensates, each of which is damped by (Λ_M/M_{Pl}). The chiral families $q_{L,R}^i$ acquire masses primarily through their mixings with the vector-like families $Q_{L,R}$ and $Q'_{L,R}$ which are induced by $< \bar{\psi}^a\psi^a >$. Thus, dropping the direct and $Q - Q'$ mixing mass terms, and ignoring QCD corrections for the quarks for a moment, the Dirac-mass matrices of the five families for all four sectors -

i.e., q_u, q_d, l and ν - have the form [6,9]:

$$
M_{f,c}^{(o)} = \begin{array}{c} \\ \bar{q}_R^i \\ \bar{Q}_R \\ \bar{Q}_R' \end{array} \overset{\begin{array}{ccc} q_L^i & Q_L & Q_L' \end{array}}{\left(\begin{array}{ccc} O & X\kappa_f & Y\kappa_c \\ Y'^\dagger\kappa_c & \kappa_\lambda & O \\ X'^\dagger\kappa_f & O & \kappa_\lambda \end{array} \right)} \tag{2}
$$

The index i runs over three families. The entities X, Y, X' and Y' are three-component column matrices in the chiral family-space having entries which are a of order unity. In the above, $\kappa_f \equiv \mathcal{O}(a_{\psi_f})\Lambda_M(\Lambda_M/M_{Pl})$, $\kappa_c \equiv \mathcal{O}(a_{\psi_c})\Lambda_M(\Lambda_M/M_{Pl})$ and $\kappa_\lambda \equiv \mathcal{O}(a_\lambda)\Lambda_M(\Lambda_M/M_{Pl})$. Since ψ's are in fundamental and λ's in adjoint representation, we expect κ_λ somewhat larger than $\kappa_{f,c}$ – i.e., $\kappa_\lambda \sim 1\ TeV \approx (3-10)\kappa_{f,c}$. As a result, the Dirac mass-matrices of all four sectors have *a natural see-saw structure*.

In the absence of electroweak and QCD corrections, due to left-right symmetry and full flavor-color independence of the metacolor force, *not only $X^T = (X')^T$ and $Y^T = (Y')^T$, but the same X, Y and κ_λ apply to all four sectors: up, down, charged leptons and neutrinos.* Furthermore, ignoring electroweak corrections (of order 5-10%) for a moment, one can always rotate the chiral quark or lepton fields q_R^i and q_L^i to bring the row matrices $Y^T = (Y')^T$ to the simple form $(0,0,1)$ and simultaneously $X^T = (X')^T$ to the form $(0, p, 1)$, with redefined κ_f and κ_c. Note the consequent great reduction even in effective parameters. Upon examining the relevant preon-diagrams, one can argue that the effective parameter p is less but not very much smaller than one. A value of $p \simeq 1/3$ to $1/5$ is found to be quite natural.

Now, it may be seen that although the three chiral families are on par as regards their binding and preon-content and thus the three entries in the X and likewise in the Y-matrices in the unrotated form (1) are expected to be comparable to each other, *the rank of the 5×5 mass-matrix, given by (1), automatically guarantees one linear combination , made primarily of the three chiral families, to be massless, barring corrections of order $(\frac{1}{10} - 1)\ MeV$, which may be identified with the electron family [9].* At the same time the heaviest chiral fermion (top) acquires a mass (in the above gross picture) of order 100-160 GeV. In fact, we obtain (suppressing EW and QCD corrections):

$$
m_{u,d,e,\tilde{\nu}_e}^{(0)} \simeq 0 + \mathcal{O}\ (\frac{1}{10} - 1\ MeV)
$$
$$
m_{c,s,\mu,\tilde{\nu}_\mu}^{(0)} \simeq (\kappa_f\kappa_c/\kappa_\lambda)(p^2/2)
$$
$$
m_{t,b,\tau,\tilde{\nu}_\tau}^{(0)} \simeq 2(\kappa_f\kappa_c/\kappa_\lambda) \tag{3}
$$

Here, $m_{\tilde{\nu}_i}^{(0)}$ denote the Dirac masses of the three neutrinos, which, combined with the very heavy Majorana masses ($\sim \Lambda_M$) of the right-handed neutrinos gives the very light ($\lesssim (1-50)eV$) left-handed neutrinos. For the $\mu - \tau$ mass-ratios, with universal p, we thus obtain: $[m_{c,s,\mu}^{(0)}/m_{t,b,\tau}^{(0)}] \approx p^2/4$. For $p \approx 1/3$ to $1/5$, which is not too small and natural, one obtains a large $\mu - \tau$ hierarchy of 1/36 to 1/100, as observed. In this way, one obtains *a very simple reason* for the inter-family mass-hierarchy – i.e., why $m_{u,d,e} \ll m_{c,s,\mu} \ll m_{t,b\tau}$. In particular, one understands the gross pattern why $m_e \sim 1\ MeV$, while $m_t \sim 100 - 160\ GeV$, so that $(m_e/m_t) \sim 10^{-5}$. This is a major achievement of the preonic approach.

In general, the effective parameter p for quarks can differ from that for leptons at Λ_M, by as much as perhaps a factor of 2, especially if $SU(3)^c$ rather than $SU(4)^c$ is the gauge

symmetry near the Planck scale. Unless electroweak corrections are substantially larger than (the expected) 5-10%, larger values of $m_t \approx 160 - 180 \ GeV$ would suggest $p(quark) \approx 1/4$ to $1/5$, while $p(leptons) \approx 1/3$. The preon model can not, of course, predict precise numbers including electroweak and QCD corrections at Λ_M, because they depend upon strong interaction matrix elements of preonic operators. But it does explain the *gross features* of the inter-family mass-hierarchy, including the small number (m_e/m_t), based entirely on symmetries of the theory, and thereby has removed the biggest surprises of the fermion mass matrix. The simplicity of the explanation lends support not only for the preonic approach but also for the existence of the two vector-like families, with masses of order $200 \ GeV - 1 \ TeV$, which are crucial to the explanation of the inter-family mass-hierarchy. Fortunately, these two families, especially their quark-members, can be probed at the LHC and (the leptonic members) at the NLC.

It turns out that by including electroweak corrections which break left-right and up-down symmetries (so that $X \neq X'$ and $Y \neq Y'$) as well as the direct mass-terms of the three chiral families in the top-left 3×3 block of (2), which are of order 1 MeV, one also obtains a desirable pattern for CKM mixings and the deviation from the universal $\mu - \tau$ hierarchy ratio of $p^2/4$, as desired [9].

(4) **A Unification of Scales:** It is shown [6] that the model is capable of generating all the diverse scales – from M_{Planck} to m_ν – and thereby the small numbers such as $(m_W/m_{pl}) \sim (m_t/M_{pl}) \sim 10^{-17}, (m_C/M_{pl}) \sim 10^{-19}, (m_e/M_{pl}) \sim 10^{-22}$, and $(m_\nu/M_{pl}) < 10^{-27}$ – *in terms of just one fundamental input parameter*: the coupling constant α_M associated with the metacolor force. Corresponding to an input value $\overline{\alpha}_M \approx 1/27$ to $1/32$ at $M_{Pl}/10$, the metacolor force generated by $SU(N)_M$ becomes strong at a scale $\Lambda_M \approx 10^{11} GeV$ for N=5 to 6. Thus the first big step in the hierarchical ladder leading to the small number $(\Lambda_M/M_{Pl}) \sim 10^{-8}$ arises naturally through renormalization group equations due to the slow logarithmic growth of $\overline{\alpha}_M$ and its perturbative input value at $M_{Pl}/10$.

The next step arises due to the constraint on SUSY breaking, which is forbidden [30], except for the presence of gravity. As mentioned before, SUSY-breaking condensates like $\langle \lambda\lambda \rangle$ and $\langle \bar{\psi}\psi \rangle$ are thus naturally damped by (Λ_M/M_{Pl})[7]. These induce (a) SUSY-breaking mass-splittings $\delta m_S \sim \mathcal{O}(\Lambda_M(\Lambda_M/M_{Pl})) \sim \mathcal{O}(1 \ TeV)$ and (b) $m_W \sim m_t \sim (1/10)\mathcal{O}(\Lambda_M(\Lambda_M/M_{Pl})) \sim \mathcal{O}(100 \ GeV)$. Note the natural origin of the small numbers: $(\delta m_s/M_{Pl}) \sim 10^{-16}$ and $(m_W/M_{Pl}) \sim 10^{-17}$. As also noted above, symmetries of the 5×5 fermion mass-matrix take us down to still lower scales – in particular to $m_e \sim \mathcal{O}(1 \ MeV)$, thus accounting for the tiny number $(m_e/M_{Pl}) \sim 10^{-22}$.

Finally, the familiar see-saw mechanism for neutrinos with $m(\nu_R^i) \sim \Lambda_M \sim 10^{11} \ GeV$ and $m(\nu^i)_{Dirac} \propto \Lambda_M(\Lambda_M/M_{Pl})$ yields $m(\nu_L^i) \leq 10^{-3} \ M_{Pl}(\Lambda_M/M_{Pl})^3 \sim 10^{-27}M_{Pl}$. In this way, the model provides a *common origin* of all the diverse mass scales – from M_{Pl} to m_ν, and of the associated small numbers, as desired [6]. This constitutes a unification of scales which is fundamentally as important as the unification of forces.

(5) **CP Violation:** The model provides an elegant mechanism for spontaneous CP violation, which is shown to vanish (for the observed processes), if the masses of the electron family were set to zero [9], – i.e. if the direct mass terms of the chiral families $m_{(0)}(q_L^i \to q_R^j)$ in (1) are put strictly to zero. Allowing for these direct mass-terms the model predicts $|\epsilon| \sim (m_d/m_b) \sin \xi \sim 2 \times 10^{-3}$ for a maximal CP violating phase. It also predicts an electric dipole moment for the neutron $\approx (1$ to $\frac{1}{20}) \times 10^{-25} ecm$, which is observable.

(6) **A Grand Fiesta of New Physics at** 10^{11} GeV**:** The preonic approach identifies the 10^{11} GeV scale as its scale parameter Λ_M. That Λ_M ought to be of order 10^{11} GeV is in fact determined within the model on two independent grounds. First, because, in the model, one obtains $m_W \sim \left(\frac{1}{10}\right) \Lambda_M(\Lambda_M/M_{Pl})$. Equating this to 80 GeV, one obtains $\Lambda_M \sim 10^{11}$ GeV. Second, it turns out that a meeting of the coupling constants is possible provided $\Lambda_M \sim 10^{11}$ GeV [24]. A variety of phenomena thus occur at the scale 10^{11} GeV (see Fig. 2): (a) First, the metacolor force becomes strong at this scale; (b) thereby, the composite quarks and leptons as well as the composite Higgses – i.e, the condensates – are born; (c) the condensates in turn break certain gauge and global symmetries of the model at the scale Λ_M while preserving SUSY (this includes $G_{224} \rightarrow G_{213}$); (d) in the process, the condensates also break spontaneously certain fundamental symmetries at the scale Λ_M which include (i) parity, (ii) CP, (iii) B-L and, as it turns out, (iv) the Peccei-Quinn symmetry as well [32]; and last but not least, (e) subject to a damping by the factor (Λ_M/M_{Pl}), the condensates also break SUSY as well as the electroweak symmetry, thereby giving desired masses $(\lesssim 1\ TeV)$ to the missing SUSY partners, W and Z and the quarks and leptons. As mentioned before, the breaking of $B - L$ occurs in a way that gives heavy Majorana masses $\sim \Lambda_M$ to the composite ν_R's. Finally, the preonic approach must also identify 10^{11} GeV as the *scale for inflation*, and $B - L$ violating baryo or leptogenesis, because 10^{11} GeV is the only scale available within the model, below Planck scale, which could be relevant to the necessary phase transition [33].

We see here that there is an enormous *economy of tools*: One and the same tool – SUSY metacolor force coupled with gravity – generates dynamically all these phenomena.

It is furthermore interesting to note that, having determined Λ_M on two independent grounds *the preon model in fact predicts that the PQ symmetry breaking scale as well as the Majorana mass of the ν_R's are necessarily both of order* 10^{11} GeV. It is remarkable that both (i) the see-saw pattern for light neutrino masses that is relevant to the MSW explanation for the solar neutrino puzzle, together with the candidacy of ν^τ for hot dark matter, and independently (ii) astrophysical constraints on the axion restrict the relevant scale in each case also to about $10^{11} - 10^{12}$ GeV. In summary, the preonic approach provides a genuine motivation for the 10^{11} GeV-scale and synthesizes a lot of new physics in terms of this single scale. We regard this feature an advantage of the preonic approach.

(7) Some Consequences and A Crucial Prediction:

(i) $m_t \approx (100 - 180)\ GeV$ [34].

(ii) New contributions to $K^0 \leftrightarrow \bar{K}^0$ and $K_L \rightarrow \bar{\mu}e$ from box graphs involving quarks and W's as well as tree-level Z-exchanges are smaller than the corresponding contributions from the SM by 1 to 2 orders of magnitude, while those for $B^0 - \bar{B}^0$ are comparable to those of the SM. Box diagrams containing squarks and gluinos would be safe, as in all SUSY theories, *if* squarks of different generations are sufficiently degenerate (e.g., to better than 5% if $m_{\tilde{q}} \sim \mathcal{O}(3\ TeV)$). Such a degeneracy could arise depending upon relative values of certain matrix elements of preon-operators, but it is not *a priori* guaranteed by the model.

(iii) $A(``Z'' \rightarrow t\bar{c}) = A(t \rightarrow Zc) \approx \left(\frac{g_2}{\cos\theta_W}\right) \left(\frac{\kappa_u}{\kappa_\lambda}\right)^2 \left(\frac{p}{2}\right) \approx \left(\frac{g_2}{\cos\theta_W}\right) (1/2 \cdot 5\ \text{to}\ 1/10)\,\%$, with $(\kappa_u/\kappa_\lambda) \approx (1/10\ \text{to}\ 1/5)$ and $p \approx 1/5$.

(iv) $\Delta m(D - \bar{D})_{preon} \approx (1/2 - 2) \times 10^{-14}\ GeV$, while $\Delta m_{(expt)} \lesssim 1 \cdot 3 \times 10^{-13}\ GeV$ and

$\Delta m(SM) \approx (1 - 4) \times 10^{-15} \; GeV$ [9].

(v) $A(Z \to \bar{\mu}e)$ which gives $B(\mu \to 3e) \approx (1 \, to \, 5) \times 10^{-13}$ [9].

(vi) $\tau_\tau = \tau_\tau(SM)(1+\epsilon) = \tau_\tau(SM)[1+(.01 \; to \; .04]$, while $N_\nu(LEP) = 3-2\epsilon = 3-(.02 \; to \; .08)$, where $\epsilon \equiv (\kappa_u/\kappa_\lambda)^2 \approx (1/10 - 1/5)^2$. Compare with $N_\nu(LEP)_{expt} = 2.988 \pm .023$. Note that the corrections to τ_τ and N_ν are correlated [35].

(vii) prominent $\nu_\mu - \nu_\tau$ oscillations with $m(\nu_\tau) \approx 1$ to $50 \; eV$, $m(\nu_\mu) \approx (10^{-3} - 10^{-1})eV$, $m(\nu_e) \approx 10^{-8}eV$ and $\nu_\mu - \nu_e$ mixing consistent with MSW solution [36].

(viii) $(edm)_n \approx (10 - 1/2) \times 10^{-26} ecm$ [9].

(ix) Existence of SUSY partners with masses $\approx 100 \; GeV - 2 \; TeV$ and two Higgs doublets corresponding to $\tan\beta \approx 30 - 40$.

(x) <u>A Crucial Prediction and Hallmark of the Model</u>: There must exist precisely two *complete* vector-like quark-lepton families (no more, no less) with masses: $m(E, E', N, N') \approx (150 - 700)GeV$; $m(U, D, U', D') \approx (350 - 1700) \; GeV$ [6-9, 37]. *They are not only predicted by the model, but they serve an essential purpose in generating masses for the observed quarks and leptons and also explaining their inter-family mass-hierarchy.* Furthermore, their existence is fully compatible with measurements of the ρ and the S (or ϵ_3) parameters, because their masses are $SU(2)_L \times U(1)$-symmetric.

For these reasons, I believe that it is a *good bet* that precisely two vector-like families – especially the quark members – await discovery at the LHC and certainly at a future version of the SSC. Likewise, the leptonic members (N, N', E, E') await discovery at the next linear e^-e^+ collider ($E_{cM} \approx 500 \; GeV - 1 \; TeV$). If light enough, they can even be produced singly at LEP 200 [37]: $e^-e^+ \to N + \bar{\nu}_\tau \to (Z + \nu_\tau) + \bar{\nu}_\tau \to (e^-e^+)_Z + \nu_\tau + \bar{\nu}_\tau$.

(8.) **Supersymmetry Breaking:** The preonic theory requires the presence of a new metacolor force which becomes strong at a superheavy scale $\Lambda_M >> 1 \; TeV$. This force influences *directly* the observed sector of quarks, leptons and Higgs bosons, since it operates on their constituents – the preons. This is analogous to QCD influencing observed hadrons. The existence of such a force, in the presence of gravity, allows the possibility of a dynamical breaking of supersymmetry directly in the observable sector (albeit with a damping by the Planck mass), which thus transmits efficiently into the masses of the squarks, the gluinos and the winos. This may well be an advantage over a dynamical breaking of supersymmetry occurring entirely in the hidden sector of a superstring theory, which seems to be the only possibility in such a theory if quarks and leptons are elementary. For a preonic theory on the other hand, assuming that it arises from a superstring theory, there is the general possibility that SUSY-breaking has its roots in both the observable and the hidden sectors and the two breakings influence each other. Alternatively, the breaking in one sector may drive that in the other. Even though SUSY-breaking effects induced through the hidden sector are expected to be small compared to M_{Pl} (and perhaps also Λ_M), they may still have significant effects in removing certain degeneracies (flat directions) and thereby influencing the dynamics in the observable sector (see remarks at the end of Ref. 26).

4. Unity of Forces at the Preon Level

Although the derivation of a preon model resembling that proposed in Ref. 6 from a superstring theory is still awaited, it is intriguing to ask whether the coupling constants g_1, g_2 and g_3 extrapolated in the context of the preon model from their measured values at low energies do indeed meet with each other as well as with g_M near the Planck scale,

for any reasonable choice of the metacolor gauge symmetry G_M and the flavor-color gauge symmetry G_{fc} which operates near the Planck scale. The precise nature of G_M and G_{fc} may hopefully get determined ultimately by an underlying superstring theory, if preons have their origin from such a theory. In this case, despite the non-unifying appearance of the effective symmetry $G_M \times G_{fc}$, the constraints of grand unification including the quantization of electric charge and the familiar equality of the coupling constants near the unification scale M_{SU} would still hold, especially for $k = 1$ Kac-Moody algebra, barring, of course, Planck-scale threshold effects.

Note that the extrapolation based on renormalization group equations is fully determined in regions I and II(see Fig. 3) because the spectrum and the gauge symmetry are fixed, while in region III, there is only a few discrete choices which can be made as regards the metacolor gauge symmetry G_M and the flavor-color gauge symmetry G_{fc}. The scale Λ_M is fixed at about 10^{11} GeV (within a factor of 3, say) by requiring consistency with the hierarchy of scales, in particular by the observed mass of m_W.

Babu, Parida and I [24,38] found that with the measured low-energy values of g_1, g_2 and g_3 at LEP and thus with $\sin^2 \theta_W \simeq .2333, \alpha = 1/127.9$ and $\alpha_3 = .118$ at m_Z as inputs, the coupling constants including g_M, show a clear tendency to converge to a common value within a few percent of each other for $G_M = SU(5)_M$ [24], as well as $G_M = SU(6)_M$ (with the inclusion of threshold effects at Λ_M [38]) at a scale $M_U \approx (2-5) \times 10^{18}$ GeV, for example for the choice $G_{fc} = SU(2)_L \times U(1)_{I_{3R}} \times SU(4)^c$, (see Fig. 2). Such a convergence, which is clearly non-trivial, demonstrates that the unity of forces may well occur at the level of preons in a manner that is truly novel compared to the conventional approach of elementary quarks and leptons.

5. Summary and Concluding Remarks

The preonic approach which has evolved in isolation over the last few years [6-9,24] exhibits some very desirable properties: (i) Utilizing local supersymmetry to its advantage, it seems capable of addressing the issues of the origin of families, and in particular that of inter-family mass-hierarchy and diverse mass-scales. (ii) It provides the scope for synthesizing a rich variety of phenomena as having a *common origin* at Λ_M (see Fig. 2). (iii) It is viable. And, (iv) most important, it is falsifiable. As such I believe, despite its unconventional status, that there is a good chance that it may even possess a certain degree of truth and that it may well provide the right effective theory to describe physics between the Planck scale and Λ_M. It should still (and I believe it must if it is the right theory) have its origin within a superstring theory, which should provide a good quantum theory of gravity and a unified origin of all the forces including gravity. The superstring theory, in this case, would need to yield the preonic spectrum and its gauge symmetry, but it would be relieved from the burden of yielding the right package of Higgs-sector parameters, because there is no elementary Higgs sector in the preonic approach.

The main disadvantage of the preonic approach at present is that it rests on two dynamical assumptions. As stated before, they are: (i) The asymptotically free SUSY metacolor force (with $N_F = N, N+1$, or $N+2$ and $m = 0$) confines and (ii) the metacolor force, combined with the (weaker) flavor-color forces, breaks the original global symmetry, that contains the flavor-color gauge symmetry G_{fc} (which could be either G_{224}, G_{2213}, G_{214} or even G_{213}), into just the SM symmetry G_{213} at Λ_M. This second assumption requires that at least the relevant class of locally supersymmetric QCD theories (unlike ordinary QCD)

break vectorial symmetries such as isospin (this induces $\kappa_d \neq \kappa_u$ at Λ_M) and preon number, as well as parity (if $G_{fc} = G_{224}$). It is a challenge to show that these symmetries are indeed broken in certain locally supersymmetric QCD theories. A positive (or negative) result in this respect will strongly favor (or disfavor) the preonic approach. Ascertaining the answer to this issue is thus a major task for this approach.

On the positive side, while the pattern of condensates (e.g., the formation of $\langle \Delta_R \rangle$) need to be assumed within the preonic approach, the scales of the condensates including those with a damping by (Λ_M/M_{Pl}) are motivated on general grounds. Furthermore, even without being derived so far from a superstring theory, *it is still the most economical model around.* In addition, it provides, as mentioned above, simple explanations for certain major puzzles, which the conventional approach so far has not. As such, I believe, it deserves far more attention as regards the study of all its aspects, in particular those involving properties of locally supersymmetric QCD theories, than it has received so far. Furthermore, its derivation from a superstring theory (including variants – e.g., as regards choice of metacolor and flavor-color gauge symmetries) is, of course, most desirable.

An additional remark, if the preonic ideas presented here turn out to be right (at least in essence), *one would clearly need an understanding of the internal dynamics of highly relativistic composite systems possessing confinement, for which the constituents as well as the composites are essentially massless compared to the compositeness scale.* Our familiar ideas about bound states (not to mention potential models) will clearly not apply. And one would need a new SUSY QCD bag model, which may be as novel relative to the idea of the QCD bag as the latter is relative to our view of the composite nuclei,bound by short-range forces without confinement, and likewise the nuclei (bound by short range forces) are relative to the atoms. In short, based on past experiences, it is not unreasonable to expect novelty at every stage of compositeness. The question is: have we exhausted the bag of such novelties, or, is there still more to come?

Before concluding, it is worth recalling that there have been occasions where the idea of a certain symmetry has turned out to be right, yet it did not progress for quite a while because of its association with the wrong fields. In particular, the idea of the Yang-Mills symmetry which was originally associated with the isospin degree of freedom of the observed proton and neutron and that of the SU(3)-flavor symmetry which in the beginning was associated with the observed $(p, n$ and $\Lambda)$ as triplet, are both examples of this kind. These ideas did not succeed until it was realized that they ought to be associated with the *constituents* of $(p, n$ and $\Lambda)$ – i.e., quarks with color. One may thus wonder whether the ideas of superstrings and grand unification ought to be associated with the observed quarks and leptons, or with a new layer of constituents – the preons. I believe that the examples cited above call for some caution in the conventional view in this regard and warrants an *open point of view.*

To conclude, if there is something that I feel more certain about, in addition to the existence of the conventional SUSY and the Higgs particles, it is the existence of the two vector-like families [6-9]. This is because of the compelling nature of their origin and the simplicity with which they explain the inter-family mass hierarchy. In spite of the promising features of the preonic approach, there is of course a good chance that one may be fooling oneself about its prospects. *How can one really tell?* In answer to this question, it is comforting to know that the approach provides at least one crucial test. *The existence or non-existence of the two vector-like families in the mass-range of a few hundred GeV to*

about 2 TeV would vindicate or totally falsify the preonic approach, as presented here. There are, of course, other intriguing flavor-changing effects which could show, at LEPI, LEP II or Tevatron (see Sec. 3.7). It is a great relief that the LHC has finally been approved and there is good prospect for approval of the NLC in Japan. These can search for the Higgses, SUSY *and* the vector-like families. It is these experimental facilities which could ultimately free us from the present bottleneck in particle physics and hopefully tell us which of our preconceived notions about elementary particles are right, if any, and which are wrong.

6. Acknowledgements

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[26] Using the power of holomorphy, N. Seiberg has recently studied extensively the vacuum properties of a large class of strongly interacting SUSY gauge theories [N. Seiberg, IASSNS-HEP-94/57, Pascos '94 talk and references therein], including the cases of relevance to us – i.e., $N_f = N$, $N + 1$ or $N + 2$. Allowing for (a) possible disconnected branches to go near the origin of scalar field-space, (b) the presence of flavor-color gauge interactions, and (c) the fact that a minimum of three-body (like $\sigma_{\mu\nu}\psi\varphi^* v_{\mu\nu}$) rather than two-body ($\psi\varphi^*$) composites seem to be needed for dynamical consistency of massless spin-1/2 composites made of massless spin-1/2 and spin-0 constituents [31,8], I have not yet been able to disentangle whether the symmetry breaking pattern $G \rightarrow G_{213}$, or rather

$G_{exact} = [(G_{fc})_{gauge} \times U(1)_V \times U(1)_X] \to G_{213}$ (where G_{fc} may even be as small as just G_{213}), which I assume, and also the associated spectrum of chiral *and* vector-like families obtained in Ref. 8, is compatible with Seiberg's analysis or not. Note that the masses of these chiral and vector-like families are protected by SUSY and the massless spectrum satisfies the 't Hooft anomaly-matching condition because the unbroken symmetry G_{213} belongs to G_{224}, which governs the spectrum, and is anomaly-free. One last remark: Soft SUSY-breaking scalar preon $(mass)^2$-term of the form $m_0^2 \sum_a (|\varphi_L^a|^2 + |\varphi_R^a|^2)$ is in general expected to be induced near the Planck scale through the superstring-generated hidden sector dynamics (as in the conventional approach). Considering that such mass-terms remove the degeneracy and favor the solution near $\varphi_{L,R} = 0$, the question arises as to how they would affect the Seiberg analysis, which is based on extrapolating from $\varphi_{L,R} = \propto$ to zero. In spite of such mass-terms, one of the main features of the preonic approach, that rests on the damping of $\langle \bar{\psi}\psi \rangle$ and $\langle \lambda\lambda \rangle$ by the Planck mass (see text) should, however, still hold, especially if $m_0 \lesssim \Lambda_M (\Lambda_m/M_{Pl})$. These questions are under investigation.

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Figure 2

A grand fiesta of new physics at 10^{11} GeV: The preonic approach suggests the existence of a rich variety of new physics, listed above, at the 10^{11} GeV scale, all of which could have a *common origin* through one and the same source: the locally supersymmetric metacolor force, operating in the observable sector, with a scale-parameter $\Lambda_M \sim 10^{11}$ GeV. As the metacolor force becomes strong at this scale, it generates the set of phenomena,depicted above, some of which preserve SUSY (such as the breakings of $SU(4)^c$, B-L and PQ symmetry) and some which do not (such as δm_s, m_q and m_W). Since SUSY-breaking effects *need* the collaboration of gravity (even though perturbative) with the metacolor force, they are naturally damped compared to the metacolor scale by the gravitational coupling. Thus arises the hierarchy of scales – e.g., $m_W \sim m_t \sim \delta m_s \sim \Lambda_M(\Lambda_M/M_{Pl}) \sim M_{Pl}(\Lambda_M/M_{Pl})^2 \ll M_{Pl}$.
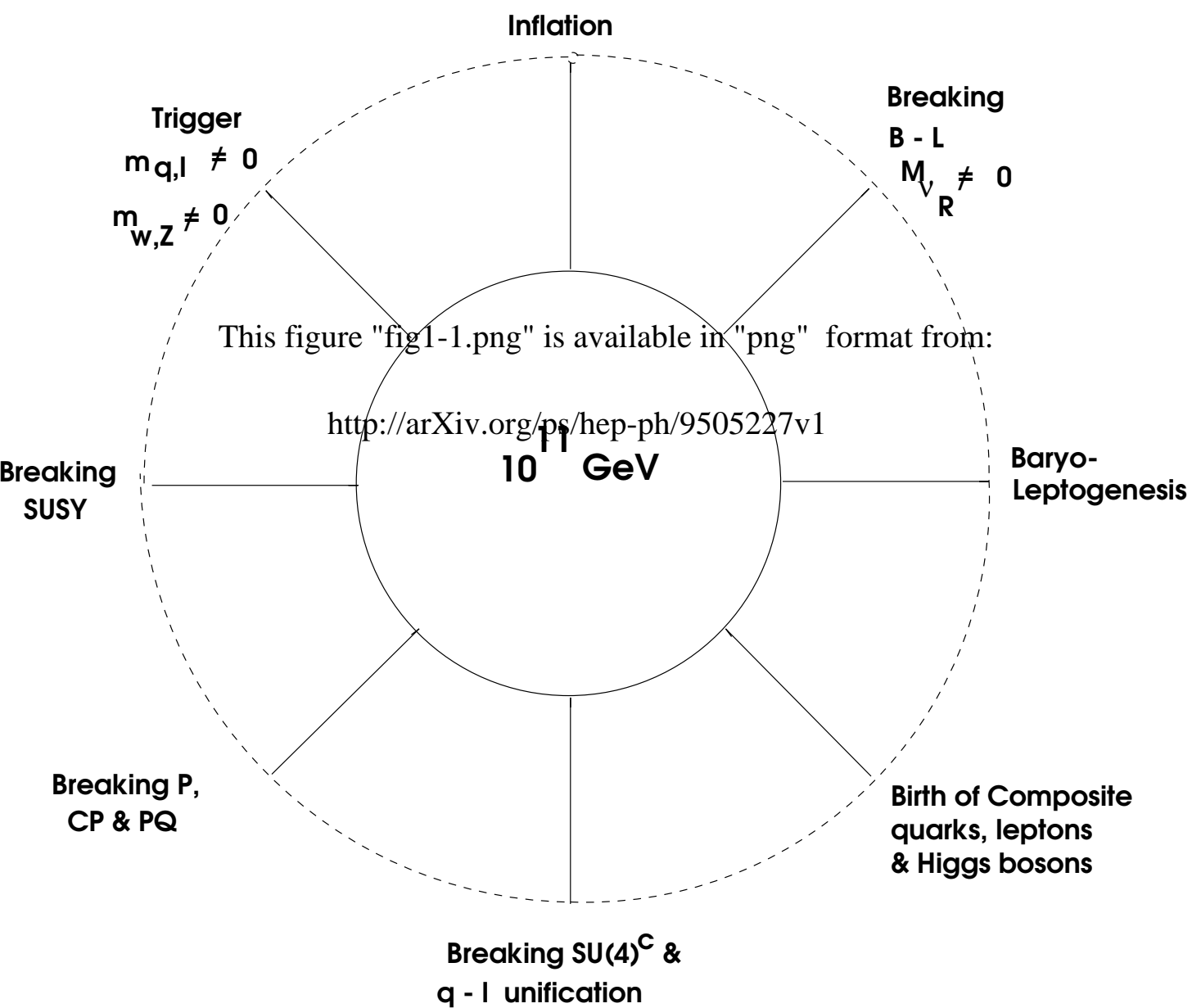
Inflation

Breaking
B - L
$M_{\nu_R} \neq 0$

Trigger
$m_{q,l} \neq 0$
$m_{w,z} \neq 0$

This figure "fig1-1.png" is available in "png" format from:

http://arXiv.org/ps/hep-ph/9505227v1

10^{11} GeV

Breaking
SUSY

Baryo-
Leptogenesis

Breaking P,
CP & PQ

Birth of Composite
quarks, leptons
& Higgs bosons

Breaking SU(4)^C &
q - l unification

Fig. 2: A Grand Fiesta of New Physics at 10^{11} GeV

This figure "fig2-1.png" is available in "png" format from:

http://arXiv.org/ps/hep-ph/9505227v1